ASSESSING THE VIABILITY OF THE ACT NATURAL GAS DISTRIBUTION NETWORK FOR REUSE AS A HYDROGEN DISTRIBUTION NETWORK

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ABSTRACT

The Australian Capital Territory (ACT) has legislated and aims to be net zero emissions by 2045. Therefore, we need to understand now the impacts on the gas distribution network of the transition to 100% hydrogen.
To assess the viability of decarbonising ACT gas networks based on the cost of reusing the ACT gas network for the safe and reliable distribution of hydrogen requires each element of the natural gas safety management system to be evaluated and where gaps in capability are identified, appropriate measures taken to ensure ongoing validity of the safety case.
Evoenergy (the ACT's gas distribution company) have constructed a Test Facility, incorporating an electrolyser, a gas supply pressure reduction and mixing skid a replica gas network and a domestic installation with gas appliances. Jointly with Australian National University (ANU) and Canberra Institute of Technology (CIT) the Company has commenced a program of "bench testing", initially with 100% hydrogen to identify gaps in the safety case specifically focusing on the materials, work practices and safety systems in the ACT.

The facility is designed to assess:

- Materials in use including aged network materials and components
- Construction and installation techniques both greenfield and live gas work
- Purging and filling techniques
- Leak detection both underground and above ground
- Emergency response and make safe techniques
- Issues associated with use of hydrogen in light commercial and domestic appliances.

To educate and train:

- Technicians and gas fitters on infrastructure installation and management
- Emergency response services on responding to hydrogen related emergencies in a network environment; and
- manage public perceptions of hydrogen in a network environment.

Australia has an enviable safety record for the safe and reliable transport, distribution and use of natural gas. The ACT natural gas network owned and operated by Evoenergy is one of the newest in Australia and has leveraged off the best materials and practices in Australia to build its network.
The paper addresses major safety issues relating to the production/storage, distribution and consumer end use of hydrogen injected into existing gas distribution networks. The analysis is guided by the Safety Management System. The Hydrogen Testing Facility described in the paper provide tools for evaluation of hydrogen safety matters in the ACT and Australia-wide.

1.0 INTRODUCTION

Decarbonising the gas network in the Australian Capital Territory will be necessary to meet ambitious greenhouse gas emission reduction targets set by the ACT Legislative Assembly (for zero net zero greenhouse gas emissions by 2045). The principal target (the ACT target) is to reduce greenhouse gas emissions in the ACT to achieve zero net emissions by 30 June 2045. The interim target is to reduce greenhouse gas emissions in the ACT to 40% less than 1990 emissions by 30 June 2020 [1].

Decarbonising the gas network will also help to retain value in the existing infrastructure and provide electrical energy storage and supply demand, alignment capability. Evoenergy intend to decarbonise its network utilising hydrogen and most likely a small portion of biomethane from organic waste. The major proportion 90% + being hydrogen requires evaluation of existing infrastructure, work practices, consumer, and public and emergency service's needs.

1.1 Safety Management System

The enviable safety record of Australia including the ACT has for the production, transmission, distribution and use of natural gas can be largely attributed to sound safety management frameworks and systems and processes developed over many years. The core of these frameworks is established by the Australian Standards and required by Acts and regulations around Australia. These Standards are developed collaboratively with key industry bodies, regulators, operators, consultants and suppliers.

Gas Safety Act Victoria (1997) is a relevant example. The Act sets out a "general duty on gas companies to manage and operate facilities to minimise, as far as practicable: the hazards and risks to public safety caused by interruptions to gas supply, including reinstatement of supply, and damage to property of the public caused by gas".

A key tool applied by the *Gas Safety Act* 1997 (Vic) is the requirement on gas companies to prepare *safety cases*, which are plans that explain how they intend to meet their general duties to minimise hazards to public safety under the *Gas Safety Act*. The nature of requirements to be included within in a safety case document are set out in *the Gas Safety (Safety Case) Regulations 2018 (Vic)* (updated from the previous 2008 regulations). Energy Safety Victoria argues that the new Regulations strike a balance between prescription and flexibility in the management of safety risks in the gas industry. The *Gas Safety (Safety Case) Regulations 2018* (Vic) prescribe Australian Standards 4564-2011 as the standard of quality for natural gas and thus adopts national industry codes [2].

As in Victoria other States and Territories in Australia require a "Safety Case" or equivalent regime called a Safety and Operating Plan or a Safety Management Plan. These plans require the operator to assess risk in advance and take appropriate risk mitigation actions or follow a prescribed set of requirements. These plans are extensive and deal with all areas impacted by the infrastructure, operations of the infrastructure and include normal operations, abnormal operations and emergency response.

This is designed to ensure that operators, consumers and the public are not unduly impacted by the existence and operation of gas infrastructure and that operations remains both safe and reliable over the life of the asset.

One unresolved issue is whether hydrogen is considered a prescribed 'contaminant' under AS4564 if it is considered that it falls within "other substances, to the extent that they cause damage to, or problems in the operation of pipelines or appliances…" (s.2.2(c))

Where no new law has been introduced to address hydrogen safety it is relevant to turn to international standards, and domestic standards, gas safety law and to civil liability law (i.e. tort law).

Existing regulatory frameworks such as dangerous goods legislation and gas safety laws already indirectly address the use of hydrogen. In addition to legislation, the common law of negligence and product liability is relevant to new applications of hydrogen, and the risk of litigation over failure to address reasonably foreseeable risks will be reflected in practical issues relating to insurance of companies undertaking hydrogen projects. In order to maintain insurance coverage, gas companies will need to show the exercise of due diligence by preparation of risk management plans and safety cases for hydrogen related activities, whether or not these are required by current legislation [3,4].

There are many existing Australian standards that are relevant to the transportation, storage and use of hydrogen. For example, Standards Australia AS/NZS 4645.1:2018 Gas distribution networks: Network management, which specifies the requirements for safe, reliable and sustainable management of gas distribution networks operating at less than or equal to 1050 kPa that reticulate gas to consumers. In addition, Standards Australia AS/NZS 4645.3:2018 Gas distribution networks Plastics pipe systems is relevant.

In addition, there are numerous international hydrogen safety and production standards.

Australia must decide whether to adopt or modify these international standards.

The International Organisation for Standardisation (ISO) has standards pertaining to hydrogen gas generators using water electrolysis [5]. These standards define the construction, safety and performance requirements of industrial, commercial and residential appliances using electrolysis. Standards Australia has not yet published a standard on hydrogen *production*. A search of the Standards Australia database in the Electrotechnology and Energy Sector suggests that hydrogen standards have not yet been made in Australia [6]. In this sense, Australia is lagging behind other developed countries. The British,[7] French [8], Spanish [9], Danish [10], and Netherlands [11] Standards Associations have all adopted at least one of the ISO standards on hydrogen generation.

A fundamental choice for Australian law makers is whether there should be a stand-alone National Hydrogen Act passed by the Federal Parliament and whether new provisions should be inserted into the *National Gas Act* and *National Gas Rules* (noting that these apply through mirror legislation in the majority of the States). Because gas, particularly gas safety, is also regulated on a State and Territory basis it will also be necessary to encourage regulatory reform at the sub-national level.

These safety management systems required under Federal and State legislation and Standards have been established and modified over a number of years. Changes in technology and incidents such as those at Longford, Varanus Island and San Bruno, initiate changes to relevant parts of these safety management systems.[12]

This paper covers the aspects of the Safety Management System at an operations level that Evoenergy is examining at their hydrogen test site, to determine the viability of introducing 100% hydrogen into the ACT gas network whilst maintaining the high levels of safety and reliability currently expected by ACT consumers and the community.

1.2 Test Site Objectives

Safety management systems cover the full extent of natural gas energy provision from production, transmission, distribution to end use by the consumer and the end to end lifecycle from design, construction and commissioning through to operations, maintenance and decommissioning. The Test Facility will support the development and modification of Safety Management Systems for hydrogen distribution networks,

The Evoenergy Test Facility was established to examine safe and reliable management of hydrogen in production, distribution and use. Large scale production is not a priority for the Test Facility rather evaluating the benefits of production in cross coupling the electricity and gas networks to integrate renewables and jointly optimise utilisation of the ACT electricity and gas networks. Transmission is being dealt with by the high-pressure pipeline transmission industry in collaboration with Future Fuels CRC and any impacts on the high-pressure steel in the distribution system in the ACT will be obtained through that forum.

The objective of the Test Facility is to evaluate low and medium pressure distribution and customer connection systems with up to 100% fraction of hydrogen, including:

- Materials, pipes and fittings and in particular those in use in the ACT network
- Work practices including:
    - Installation & commissioning
    - “Hot work” particular new connections
    - Pressure testing and leak detection
    - Emergency response and isolation practices
- Stakeholder engagement

2. The Test Facility

Prior to commencement of construction a risk assessment was carried out on the conceptual design to ensure all parties involved in construction and operation of the facility understood the risks involved and some aspects of the conceptual design were modified to reduce any risks to as low as practicable. The majority of the site was installed and constructed in 3 months and testing began in late December 2018.

Figure 1. Hydrogen Testing Facility

2.1 Design of the Test Facility

The conceptual design of the Test Facility is shown in Figures 2. Given the non-standard nature of the project and the short construction time frame involved, it was decided to use the conceptual design to "field fit" components into the test layout. This replicates what happens with the medium-pressure network installation in the field.

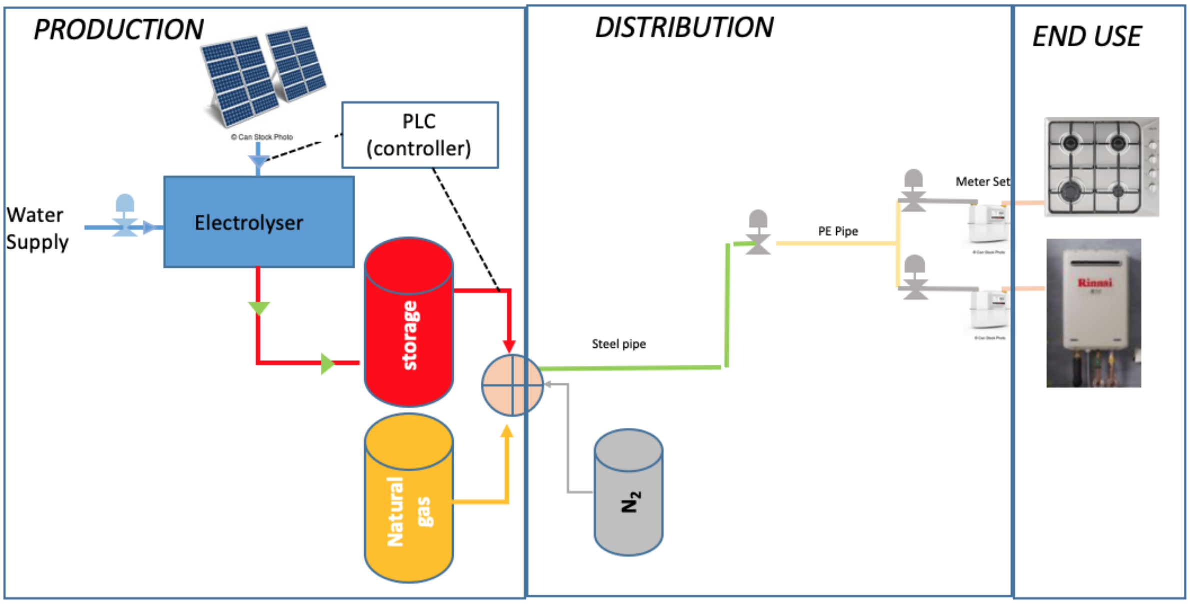

Figure 2. Conceptual diagram of the Test Facility comprising: Production, Distribution and End Use

As shown in Fig.2 the Test Facility is designed to replicate major components of hydrogen distribution network, including: Production, Distribution and End Use.

2.2 Production

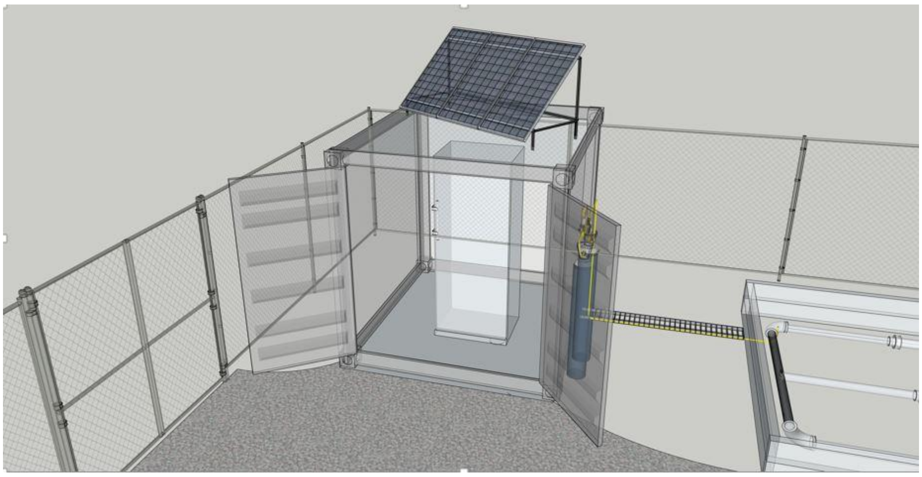

Figure 3 Hydrogen Production areas

The hydrogen production area (see Fig.3) includes a 1.2 kW alkaline electrolyser in an 8ft shipping container modified to include venting and provide a platform for a 1.2kW solar array. The electrolyser produces up to 250 litres of pure hydrogen per hour using 1.2kW of power. The electrolyser will produce hydrogen at pressures up to 35 bar and cycles storage between 30 bar and 35 bar. The electrolyser is powered by a 5.3 kW solar array split into two separate arrays. The first with 4 panels provide 1.2kW and the second with 14 panels that provide the 4.1 kW balance so that generation during low solar activity particularly in winter is possible. The arrays are selectable.
Storage is provided by two “G” size hydrogen bottles (50 litres, 13MPa), with regulators and valves to enable operation and testing of the network at distribution pressures with the green hydrogen stored from the electrolyser. Compressed Natural Gas (CNG) bottles, regulator and valves are also included to enable mixing of hydrogen with natural gas. The size of storage and production is sufficient to individually and continuously supply a cooktop for approx. 3 hours, a portable heater for 5 hours and an instantaneous hot water system for approx. 15 minutes.
The electrolyser is currently being used to produce H_2 to fill and pressurise the test network and various network components under test. In addition, a nitrogen “G” size bottle (50 litres 16MPa) is included to allow for purging and safe pressure testing of the system. A Programmable Logic Controller manages renewable power supply from solar PV panels and on-site storage of renewable hydrogen to address testing requirements.

2.3 Distribution

Figure 4. Hydrogen Distribution area

A mini network (See Fig.4) has been constructed in a sand bed using polyethylene and nylon pipe and components. There are two “runs” 1 comprising nylon pipe and fittings and the other containing polyethylene pipe and fittings. The two runs are connected by a copper pipe riser to the supply pressure control equipment to a customer meter at the end of the test bed. The type of fittings under test include, valves, saddles, "T"s, and domestic regulators and meters. This mini network is designed to simulate all the major components in the current network in the ACT. Testing is performed with both new and aged equipment and pipes removed from the existing network.

2.4 Consumer End Use

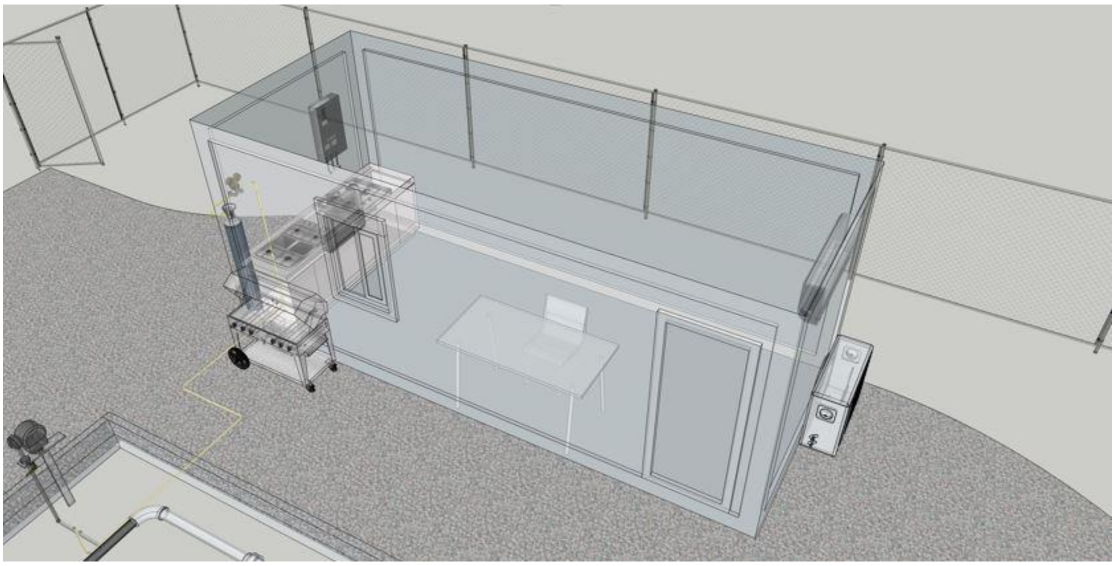

Figure 5 Consumer End Use and Appliances testing area

A 20-foot shipping container has been adapted to house the office for the site and includes an area where appliances can be connected to the outlet of the test bed network via a standard customer gas installation (See Fig.5).This allows appliances such as cooktops to be tested on hydrogen/ natural gas mixes of 5% to 100%. A hydrogen BBQ has been obtained to enable testing of the flow characteristic of the network on 100% hydrogen. Shipping containers were used to make the facility portable when testing lifecycle is complete.

3. Analysis of Safety Management System components

The gas safety management system for distribution networks is required under AS4645:2018. Evoenergy natural gas safety systems has been evaluated and the following issues were identified as important for continued safety and reliable operation of the network with hydrogen;

- Design of network and network components
- Materials
- Work practices
- Emergency response
- Issue related to key stakeholders and the public

3.1 Design and Components

The design of gas distribution network infrastructure is central to the safety and reliability of gas distribution. The Australian Standard AS4645:2018 is the primary document that establishes the requirements for gas distribution network design. The Evoenergy hydrogen Test Facility utilises the requirements established in AS4645:2018 for the design of the network components into a replica test network.

3.2 Materials

Materials utilised in the current distribution network in the ACT are reasonably modern as the network commenced construction in the early 1980s.The materials and components are common to many networks in Australia and around the world. Materials used in the Evoenergy hydrogen Test Facility are a mixture of material types such as polyethylene, nylon and copper and as many different jointing components for valves and meters as are common in the network today. Aged components removed from service are also placed under test.
Testing of long term effect of hydrogen on polyethylene has been conducted elsewhere [13] and therefore the work carried out by Evoenergy will focus on those aspects not currently being tested elsewhere such as testing of nylon and glued joints and installation practices of pipe, fittings and components used in both polyethylene and nylon and copper infrastructure.

3.3 Work Practices

A major area related to the safety and reliability of the network are the work practices in ensuring that the design and material properties are achieved. Many investigations into the use of hydrogen have focussed on materials and properties of hydrogen, However if there are substandard work practices the design and asset life and consequently business case will never be achieved. The review of work practices is a significant part of the investigation being performed at the Evoenergy hydrogen Test Facility.
For example, all network infrastructure installed at the facility has been by personnel that install the network components within the Evoenergy gas network, using the same procedures, tools and equipment, jointing compounds and leak detection procedures that are in use on the network today, the only additional piece of equipment provided is a dedicated portable hydrogen detector. As we are working in conjunction with Canberra Institute of Technology (CIT), gas fitters from CIT installed the customer piping and appliances downstream of the network meter as would be the case in a standard domestic installation.
This approach tests not only current work practices and quality but provides a basis for discussion with the next generation of gas fitters on the properties of hydrogen vs natural gas.

3.4 Emergency Response

Provision has been made in the test bed to carry out underground leak detection and location, customer hot tapping connections and squeezing off for emergency response work. The response to incidents in locating leaks, making safe in the event of a rupture or fire are aspects of the safety management system that Evoenergy considers essential to ensure that not only is the public and community safe, but that the technicians and gas fitters have the tools, techniques, skills and knowledge to manage hydrogen distribution as safely and reliably as with the current gas network. Evoenergy intends to invite emergency services to the site and demonstrate how a response to a hydrogen incident would be managed.

3.5 Stakeholder Communication and Education

The review of work practices provides a suitable forum for stakeholder engagement opportunities and many public and industry personnel such as gas fitter students have visited the site whilst in operation.

4. Testing and evaluation

Since there are many areas to be evaluated for a move to distribute and use 100% hydrogen and the level of activity in Australia and around the world has increased over the past 12 months, Evoenergy have put in place a number of mechanisms to ensure the bench testing project remains relevant and does not duplicate testing and evaluation happening elsewhere. The project has been designed as an agile project to able to jump or skip stages if the information becomes available from other sources.

These initiatives include regular reporting on the project to the peak gas industry body Energy Networks Australia (ENA) and its Gas Committee, which has representation from all gas distributors in Australia and operates in a close association with corresponding industry bodies in UK and Europe.
Australian National University (ANU) has also provided access to its laboratory testing capabilities where specific issues are to be addressed. ANU undergraduate and master's students carry out specific research projects extending the scope of the Test Facility, and utilising the Test Facility results as a corroboration of findings.
Future research efforts are expected to include:

- Modelling hydrogen behaviour in the network in the presence of impurities
- Novel storage and generation approaches
- Hydrogen sensors for spatial leak detection and information management
- Odourisation and leak detection
- Options for flame visibility
- Regulatory and legal framework and societal impacts

4.1 Testing strategy

The testing strategy was developed to address the most prevalent distribution issues potentially arising from replacing natural gas with hydrogen in the most common network infrastructure currently in the ACT network. The initial stages of the testing strategy will deal with lower volume items and any specialist equipment. Given the volume of components to be tested, it was decided to deal with domestic installations before addressing commercial installations as the fundamentals of distribution of hydrogen to the public in an intrinsically safe way is the same for distribution to commercial premises.
The initial stages are:

1. Pressure testing under nitrogen and under 100% hydrogen.
2. Evaluation of hydrogen production using a solar PV powered electrolyser and of on-site storage of renewable hydrogen.
3. Trials of mixing natural gas with hydrogen and evaluation of home appliances operations when proportion of H_2/natural gas varies.

The first stage of testing commenced in early 2019 which is simply a pressure hold test on 100% hydrogen for all the network components at the Testing Facility. This includes the development of procedure for the use of hydrogen sensors and leak test solution as any leaks are identified and located. Test pressures are set at operating pressures and the pressure and temperature monitored and recorded over a period of weeks. The volume in the test bed equals approximately 30 litres, with more than 80 fittings and 160 joints (See conceptual schematic Fig.1). This small volume makes the test setup very sensitive to temperature changes and leaks at very small leak rates which are easily detected via pressure decay.
To reduce the temperature effect and insulate the pipework and fittings they are buried in sand at a depth of at least 300mm. This also simulates the environment of the network for underground leak detection and location. Once the network pipework has been pressure tested on hydrogen the next hydrogen pressure hold test was to the network meters and regulators and the customer pipework and components downstream of the meter.
Although the Evoenergy's distributor responsibility ends at the downstream connection of the customer meter, the integrity of the customer piping is a significant part of safe delivery and use gas and Evoenergy has a responsibility not to distribute gas to a non-compliant customer installation. Therefore Evoenergy is working in collaboration with CIT who trains the gas fitters that install the customer installations in the ACT and is also testing a customer piping test setup and will test various pipe types of pipe including copper and composite pipe and other customer piping components.

4.2 Test results to date

Two tests were performed during the 3-month period 17th December to 21st March. A pressure test of 100% hydrogen on the test network and the ability and sensitivity of locating leaks with the natural gas "soapy solution" and a dedicated hydrogen detector.

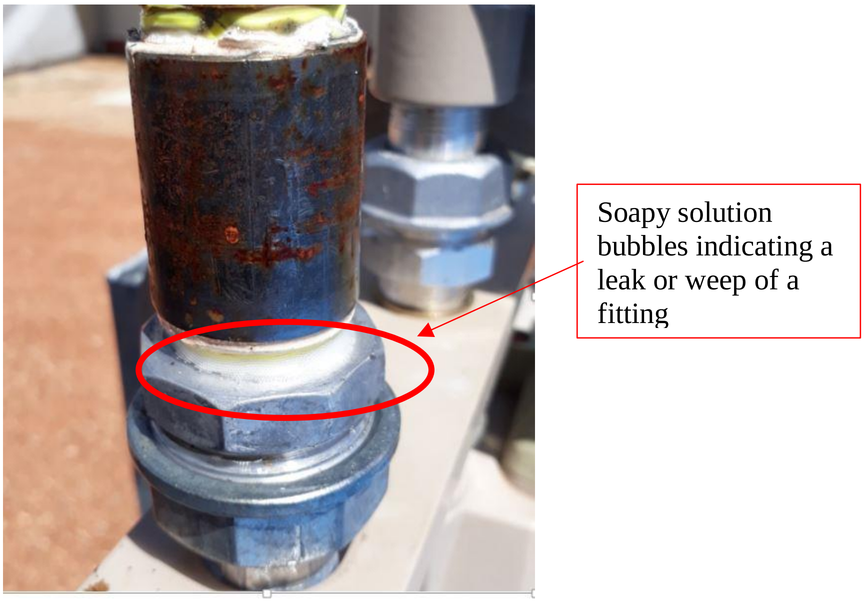

Figure 5. Leak location with "Soapy Solution"

The pressure test commenced with an integrity pressure test of the network at 110% on nitrogen and the introduction of hydrogen up to a maximum pressure of 175kPa. Readings were taken of pressure and temperature and indications after a week were that the pressure was reducing at around 5 kPa per day. A detector was used to test all exposed pipe joints and a leak was detected at 72 ppm at a steel taped fitting on the riser to the gas meter. The leak was also located with "soapy solution" (Figure 6) and repaired and pressure re-established to 175 kPa and test resumed. A number of connections were made to the end points of the test network to test valves and connect the hydrogen BBQ for demonstration purposes. Each time small quantities of hydrogen were released and the network repressurised to the test pressure 175kPa. Further reductions in pressure were noted after these connections and disconnections although at levels below 1 kPa per day and less than 0.5 % of test pressure. These have been located at the gas tape where the joint was disturbed.
Testing to date has confirmed that polyethylene and nylon pipe and their respective jointing techniques can contain 100% hydrogen at pressures used for natural gas. Testing has also confirmed that current installation work practices on polyethylene and nylon pipe and joints are suitable for hydrogen service. However, the sample of personnel used for installation was limited to two personnel and more testing would need to be carried out on the sensitivity to different personnel and weather conditions. Evoenergy intend to carry out more of this testing. In the last few weeks Evoenergy has tested gas isolation by clamping the nylon pipe under pressure and effecting a repair on the hydrogen network. This has proved that this natural gas isolation technique works with 100% hydrogen at natural gas pressures. This is an essential technique for live work repairs and emergency response make safe applications.

4.3 Further testing stages and considerations

In parallel with the hydrogen pressure test Evoenergy has established hydrogen production by electrolyser and has commenced testing storage of renewable energy from surplus solar electricity utilising the small test gas network as a buffer to shift the supply demand peaks. The Safety Management System dictates the need for solutions for odourless supply and colourless combustion of hydrogen natural gas is typically odourised by adding tetrahydrothiophene and/or mercaptans or sulphur- free odourising agents. This provides a warning smell intended to indicate to people when gas appliances are leaking, or gas is otherwise escaping unburnt.
The legal requirement for odourisation of reticulated natural gas is universal in Australia. For example, in Victoria, the *Gas Safety (Safety Case) Regulations 2018* (Vic) (ss.46) (made under the Gas Safety Act 1997 (Vic) [14]) require that gas must: (a) have an odour which is distinctive and unpleasant; and have an odour level that is discernible at one-fifth of the lower explosive limit of the gas. Since hydrogen is odourless (just like natural gas), it must be odourised for safety reasons and to comply with the regulations. An additional safety issue is that hydrogen flame is invisible. Solutions for the problem of odourless supply and colourless combustion of hydrogen must be developed and reflected in relevant standards and regulations.
The two main categories of options are adding specific substances to hydrogen distribution lines (chemical solutions) or deploying hydrogen sensor alarms and flame indicators (physical solutions). Chemical solutions are potentially complicated by **three factors**: (i) fuel cells (e.g. in FC vehicles) can be damaged by substances added to hydrogen; (ii) a separation of hydrogen and added substances is possible when substances are injected far upstream from the point of consumption (e.g. household cooktop) and (iii) the regulatory requirements (i.e. gas quality guidelines and standards) restricting the addition of substances to the gas supply network. One chemical solution approach is to inject required substances close to the point of consumption e.g. in proximity to gas meters of houses. In this way factors (i) and (ii) can be eliminated. Otherwise, physical monitoring solutions would require extremely high reliability of alarms equipped with hydrogen sensors. Thermal sensors of hydrogen flame can also be implemented in appliances to switch on light indicators (e.g. LED) depicting operational burner of the appliance. One approach to be tested is to integrate a hydrogen sensor with a fire alarm.

5.0 CONCLUSIONS

The hydrogen Test Facility is constructed by Evoenergy to conduct detailed evaluation of the requirements, issues and risks associated with the transition to hydrogen. The testing strategy is underpinned by the Gas Safety Management System, components of which are also being evaluated to understand both technical and regulatory changes that may be required to enable decarbonisation of gas distribution network in the Australian Capital Territory and Australia-wide.
Testing to date on 100% hydrogen has confirmed a number of aspects related to the introduction of 100% hydrogen into the ACT natural gas network.

1. Nylon pipe and jointing techniques (glued joints) do not indicate any tendency to leak after 6 months of exposure to 100% hydrogen at natural gas pressure.
2. Work practices to install and make safe during an emergency work using the same equipment and techniques as for natural gas.
3. Worker and public confidence is enhanced by demonstrating actual real world situations in managing hydrogen.

These three findings are critical to maintaining a safe and reliable gas network under the existing safety case. To ensure alignment with hydrogen existing Regulation and Standards called up as requirements under the Safety Case regime need to be updated as appropriate in an informed and coordinated manner.

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